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USAF SOLAR THERMAL APPLICATIONS OVERVIEW (TR-03-81)

FINAL REPORT

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ABSTRACT

This report provides a generic overview of USAF process heat applications and compares those applications to solar thermal technologies for evaluation. The first step was to assess the existing USAF data base to determine its usefulness for the problem at hand. The documentary data was augumented by visits to six USAF bases. Process heat applications at the bases were characterized and a generic data base assembled from the findings. These generic USAF process heat applications were analyzed for solar thermal technologies utilization, using SERI's PROSYS/ECONMAT model in an end-use matching analysis. A separate analysis was made for solar ponds.

The information necessary to the analysis was found to be most readily available at the base civil engineer level. Current headquarters level energy data bases are generally inadequate to detailed assessments of distributed technologies in process heat applications. The generic applications set relies heavily on base civil engineer estimates.

In general, solar technologies appear attractive in a large number of USAF applications. Positive returns on investment of up to 29 percent are projected under conservative assumptions. As expected, low temperature applications at sites with high insolation and high fuel costs are most attractive. All sites analyzed showed some applications with a positive payback potential.

No one solar thermal technology emerges as a clearly universal or preferred technology. Solar ponds, though requiring further research, offer a potentially high payoff in a few, selected applications. Troughs and flat plate systems are predicted cost effective now in a large number of applications. PFDR systems also show positive returns on investment and a near-term potential for cost reduction. Towers were not separately assessed.

A second phase of this study will yield five case studies of specific applications for solar thermal technologies.

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INTRODUCTION

It is a stated DOD and USAF objective to reduce the dependence of military installations on fossil fuels by promoting the use of more abundant resources where liquid hydrocarbons and natural gas are now used. Concerns for energy availability and rising energy prices have led to the establishment by the Engineering and Services Laboratory (ESL) of a goal of replacing 10 percent of current facilities' energy consumption with alternative fuels and 1 percent with solar and geothermal resources by 1985.

The major consumption of fossil fuels by USAF installations is to produce heat. If USAF facilities' energy goals are to be met, emphasis must therefore be placed on the test, evaluation and utilization of renewable energy systems to provide process heat and space heating. Of these two areas, the more critical to USAF mission accomplishment is that of process heat generation.

In recent years, the Jet Propulsion Laboratory has been actively pursuing the development of solar thermal technologies to meet process heat loads. Under the sponsorship of the Department of Energy, JPL is responsible for the development of parabolic dish and solar pond technologies, while Sandia Laboratories is responsible for the development of parabolic troughs and central receiver systems.

In early 1980, JPL was developing a Thermal System Engineering Experiment to test and evaluate point focussing distributed energy systems in the industrial sector. The experiment manager, Mr. Steve Bluhm, proposed a cooperative program directed toward meeting USAF/ESL energy objectives through the application of JPL-sponsored technology. What was proposed was a four phase effort, consisting of

1) USAF Applications Analysis and System Requirements Definition
2) System Design and USAF Site Selection
3) Construction and Test of an Engineering Prototype
4) Installation and Operational Evaluation of a System in a Selected USAF Application.

The value of a cooperative program was recognized by USAF/ESL. They expanded the scope of the effort to definately include a consideration of solar thermal systems in general, in the first task of the analysis. ESL then provided funds for the performance of an analysis of USAF process heat applications for solar thermal energy systems.

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In September 1980, a contract was awarded to Applied Concepts Corporation for the performance of the analytical task. Applied Concepts brought to the task a strong background in both USAF energy requirements (its principals having prepared the USAF/ESL Facilities Energy R & D Plan in 1979), and in technology applications.

The Applications Analysis and Systems Requirement Definition was organized into two tasks. The first, which was labelled "USAF Thermal Applications Overview," was designed to meet two program objectives:

1) To characterize and categorize USAF process heat applications in terms appropriate for assessing solar thermal technologies.

2) To evaluate USAF process heat applications for solar thermal technologies' utilization based on their potentials for operational effectiveness, cost effectiveness and fuel displacement.

The second, titled, "USAF Thermal Applications Case Studies" will meet the third program objective:

3) To select specific USAF sites for near term (FY 1981-1986) operational test and evaluation of solar thermal technologies.

The program approach was established to maximize limited program resources, which were small relative to the potential scope of the problem, and the uncertainty which was recognized in the level of availability of detailed information on USAF applications. The contractor was directed to make maximum use of existing USAF data in establishing and characterizing USAF process heat applications. The available information would be augmented and validated by field visits to six USAF bases. From the information thus obtained, the project team would develop a set of generic USAF IPH applications and analyze the attractiveness of solar thermal technologies against this application set. Clearly, the precise methods for selection and analysis had to depend on the nature and vitality of the data as found to be available in the literature and in the field.

The reason for the uncertainty to the research is inherent to the nature of the new technologies. Conventional fuel burning systems tend to be standard and centralized in their operation and in their management. Efficiency of operation and efficiency of control tend to be maximized with centralization. Thus, fuel can be shipped to fewer points. Support staff and record keeping can be minimized. A single, low cost plant design can be mass produced and shipped to meet many needs over a range of temperatures. Since fuels burn at several thousand degrees, heat can be produced and transported at any temperature above the highest required for process operation, and then stepped down through a heat exchanger for all other applications. Since fuel was cheap the inefficiencies

introduced by this approach were very small in their impact.

Solar technologies are different. Because energy output is a function of collector area and of available sunlight, each system must be individually sized to the application and the load. This seeming disadvantage is offset by the inherent modularity of the technology, by its potential for dispersed operation, and by the efficiencies of precise system sizing and minimization of transmission losses. The point is that different types of information, generally more precise in detail and broader in scope, are needed to assess the feasibility of solar technologies than have typically been maintained by energy managers.

This fact need not be seen as an additional burden imposed by solar technologies. The rising value of conservation -- which is generally a prerequisite to the effective utilization of solar energy -- imposes similar demands on fossil fuel energy system management. Conservation measures are, like solar applications, site dependent. Their evaluation requires new and more detailed information than we have been used to gathering. At this point in the state of the art of energy management, information management which benefits one area is likely to benefit both.

This technical report presents the results of research for Task I, "USAF Thermal Applications Overview." That task was divided by the contractual statement of work into three subtasks, which are summarized here:

1) Analyze USAF/ESL Applications Data Base

 a) Establish variables for analysis
 b) Examine the data base
 c) Recommend additions to the data base

2) Field Validate and Correlate USAF/ESL Data Base

 a) Perform six on-site analyses at specified facilities (Tinker, Robins, Lowry, MacDill, Eglin, March AFBs)
 b) Generate a special data base from observations

3) Categorize USAF Process Heat Applications and Compare to Solar Thermal Technologies

 a) Identify key factors for generic categorization
 b) Tabulate the applications
 c) Establish criteria for comparing applications to technologies

The following chapter presents the results of this work.

TECHNICAL DISCUSSION

1. General

The research and its findings may be best reported in two segments. The first is the characterization of USAF process heat applications. This includes the supporting research into the vitality of the data base which was prerequisite to the analysis. The second is the comparison of the USAF applications, as determined, to solar thermal technologies. This latter step will yield the desired product of this research task, a generic evaluation of solar technologies in USAF process heat applications.

2. USAF Process Heat Applications

a. Analytical Method

A four step methodology was established as most appropriate for the problem of characterizing USAF process heat applications for generic analysis. The most important factor to the selection of the approach was the fact that the general vitality of existing USAF data for answering the problem was only vaguely understood by either the contractor or ESL at the inception of the research.

Figure 2-1 presents a summary of the analytical method. Since the exact nature of available information on USAF applications was unknown, this approach depends on first defining what information one must have, and then seeking that information among elements of existing data sets. Figure 2-2 presents the list of data elements necessary and desirable for an analysis of solar technologies in USAF applications. The minimum information described will support a generic analysis, as was contemplated for this task. The desirable information will support specific analyses of specific applications, as is eventually desirable for USAF energy management. This is also the level of detail required for analysis of selected applications in the second phase of this research.

Once the data necessary to the research was established, the research team could pulse the existing USAF information system to determine the availability of the data. The study team visited USAF/ESL and HQS USAFLC to establish the availability of information at headquarter levels. In addition, telephone conversations were held with USAFSC and several offices at the Department of the Air Force level.

USAF APPLICATIONS

ANALYTICAL METHOD

- ESTABLISH THE VARIABLES FOR ANALYSIS
- GATHER DATA TO CHARACTERIZE USAF IPH USES
 - — SEEK EXISTING DATA ON ALL USAF IPH APPLICAIONS
 - — SEEK TO MAKE ESTIMATES BASED ON PARTIAL USAF-WIDE DATA BASES
 - — SEEK EXISTING DATA FROM BASE CIVIL ENGINEERS FOR LOCAL APPLICATIONS AND EXTRAPOLIATION
 - — SEEK TO MAKE ESTIMATES BASED ON PARTIAL INFORMATION FROM BASE CIVIL ENGINEERS.
- CHOOSE METHODOLOGY FOR ANALYSIS DEPENDING ON THE VITALITY OF THE DATA BASE
- GENERATE A SPECIAL DATA BASE FOR THE ANALYSIS FROM THE AVAILABLE INFORMATION

Figure 2-1

USAF APPLICATIONS
ANALYTICAL VARIABLES

- **MINIMUM INFORMATION FOR END-USE MATCHING**
 - PROCESS IDENTIFICATION
 - PROCESS TEMPERATURE
 - HEAT RATE
 - FLUID USED
 - DUTY CYCLE
 - FUEL DISPLACED
 - EFFICIENCY OF COMBUSTION
 - FUEL COST

- **ADDITIONAL INFORMATION FOR IMPROVED ANALYSIS**
 - SITE AVAILABILITY
 - ENERGY & MASS BALANCE
 - FEEDBACK LOOP-IMPACT ON EXISTING ENERGY PLANT
 - MISSION/AVAILABILITY PRIORITY
 - LOCAL MICROCLIMATE
 - TRANSPORT & HEAT EXCHANGE OPTIONS
 - DETAILED INTERFACE COST ANALYSIS
 - TEMP & PRESSURE VARIATION TOLERANCES
 - REGENERATION/ COGENERATION OPPORTUNITIES
 - TOTAL LOAD PROFILE

Figure 2-2

To the extent that summary data were available for an analysis (a situation which was not generally anticipated), it would be conceptually possible to make a generic analysis which was simply a summary of all specific applications. If partial, but valuable information were found existing at headquarters levels, professional estimates might make possible a solid generic analysis with a high level of confidence.

Whenever summary information was lacking at the headquarters levels, base civil engineer maintained information could be used and extrapolated. The research team and ESL anticipated a low level of headquarters' information on decentralized applications, and therefore scheduled a visit to six selected bases from the beginning of the project. Least in order of preference, but high in order of potential payoff, the site visits could yield productive professional estimates to fill in any remaining gaps in the data base.

The selection of the final methodology for comparing solar technologies to USAF applications would depend on the vitality of the existing data bases as found during the data base analyses. As an interactive step, a special data set for the analysis must then be assembled for performing the generic applications analysis using the selected methodology.

The End Use Matching Method which was used to compare USAF applications with solar technologies is described in section 3, below. The following subsections describe the availability of information as determined by research, present the USAF process heat applications which were identified, describe the generic data base which was defined for use with the End Use Matching analysis, and review the general findings of this phase of research.

b. Availability of Information

The types of information required for assessing USAF process heat applications are summarized in Figure 2-3. The figure also indicates the general level of availability of information at headquarters levels and on base. A check indicates that solid information is generally available. An E indicates that the resources exist for a reasonable professional estimate. A blank indicates a general lack of specific information for analysis or for making useable estimates. The specific sources of data are summarized in Figure 2-4.

As indicated by the first entry on Figure 2-3, there is no application-by-application inventory of process heat uses available at headquarters levels. The best, generally available, data base for this item is the Real Property Inventory Detail List which lists facilities and heat plants. It is sometimes possible to estimate applications from this data base, but generally this is not a reliable method. The study team had hoped to be able to

USAF APPLICATIONS

AVAILABILITY OF DATA

DATUM	AVAILABILITY ON BASE	AVAILABILITY HIGHER HQS
1. IDENTIFICATION OF APPLICATIONS	✓	E–
2. CHARACTERIZATION OF LOAD	E	–
3. CHARACTERIZATION OF CURRENT HEAT PLANT	✓	✓–
4. FUEL CONSUMPTION OF CURRENT HEAT PLANT	E?	–
5. FUEL PRICE	✓	✓
6. CURRENT SYSTEM O & M COSTS	E–	–
7. SITE AVAILABILITY FOR SOLAR	✓–	–
8. SOLAR THERMAL SYSTEM CHARACTERISTICS AND ECONOMICS	–	✓
9. MISSION CRITICALITY	✓	–

Figure 2-3

USAF APPLICATIONS

SPECIFIC DATA SOURCES

- HQS LEVELS
 - REAL PROPERTY INVENTORY DETAIL LIST
 - SPECIAL SURVEYS & ENERGY AUDITS
 - MAJCOM COST ACCOUNTING SUMMARIES
 - DEFENSE ENERGY INFORMATION SYSTEM (DEIS)

- BASE LEVEL
 - BCE AND USER STAFF KNOWLEDGE
 - SPECIAL STUDIES
 - PLANT BOILER OPERATING LOGS
 - BCE COST ACCOUNTING RECORDS
 - BASE ENGINEERS AUTOMATED MANAGEMENT SYSTEM (BEAMS)
 - ENERGY MONITORING AND CONTROL SYSTEM (EMCS)

Figure 2-4

use this technique to extrapolate results of the site visits USAF-wide, but the vigor of the data base was simply inadequate to the task.

The major need in either assessing or designing a solar thermal energy plant is for characterizing the load. For a complete analysis, this implies historic load profiles, energy and mass balance information, and energy input variation tolerances in addition to the minimum information of process temperature, fluid used, duty cycle and heat rate. Virtually none of this information is available at headquarters levels. Not all of it is available at the base level.

Base civil engineers and process heat users have sound data on process temperature, fluid, and duty cycle. Only rarely does measured information exist on heat rate. In some cases, special studies were available with calculated estimates of process heat rate. In others, sound estimates could be made. Only for central heat plants was measured heat output generally available. There was no reliable, precise data, however, on transmission losses or the heat consumption of individual applications which drew heat from the central plant. This lack of metered or other empirical data on USAF process heat applications represents the largest single barrier to USAF assessment of solar energy options.

Heat plants are generally well characterized and sufficient information exists on base to permit existing plants to be assessed for solar back-up and plant integration. Some of this information has been passed to ESL in the form of responses to special surveys. Limited information is contained in the Real Property Inventory Detail List.

Fuel consumption of heat plants must often be estimated. Large central plants are typically metered, but smaller boilers may not be. Current USAF metering programs are beginning to make a difference here, but the historical pattern, which still is typical, is for bases to have a single meter for billing from the supplier plus subsidiary meters for billing tenant organizations. Sometimes these bills are based on estimates, however.

Fuel prices are available at the base level and are reported upwards. Operation and maintenance costs in support of energy systems are not well understood, however. Current reporting does not distinguish between repairs and maintenance to the energy subsystem and those to the application. Interviews with Base Civil Engineer (BCE) personnel can often provide the basis for estimating O & M costs. For the purposes of this analysis, general values were assumed for O & M expenses.

Site availability is not readily determined from map analysis. The project team tested this approach and found that the information included on BCE maps was generally insufficient to accurately predict site suitability. BCE personnel can quickly and readily suggest appropriate sites for ground mounted installation. Roof areas and height restrictions are also quickly identifiable, but the study team found that load-bearing capacities for the roofs of facilities were not generally known. Special research or engineering assessments will be necessary to establish the feasibility of roof mounting in many cases.

It is worth noting at this point that the information required to assess solar applications in detail is extraordinarily site specific. Therefore, the maximum availability of information to support these assessments is on base. The project team found a general interest among BCE personnel in solar thermal technologies, and a general competence to acquire and apply knowledge of these systems. Access to information, however, is limited. Headquarters staffs are much more aware of the state of the art, which is one necessary element to evaluating solar applications, while BCE staffs are much more aware of the site specific applications information which is also necessary.

c. Applications

USAF process heat applications were identified and characterized at six selected USAF bases, with the invaluable assistance of the base civil engineers. Base and user staff knowledge, together with professional estimates of the project team, proved to be the major useful source of information for load characterization, current system O&M costs, site availability, duty cycle, mission criticality, and heat plant characterization.

In a few cases, special studies and energy audits were of help in characterizing loads and heat plants. Base Civil Engineering cost accounting records were the major source for fuel consumption, fuel price, and water consumption data.

There was an unanticipated difficulty in defining a process heat load as distinct from a space heating load. The principal methodological distinction has to do with load variation. Process heat systems are those which tend to have a duty cycle which is insensitive to season. Space conditioning tends to have a duty cycle which is highly seasonal. These distinctions seem less important when all loads are served by a central plant. Perspectives also varied according to the perceptions and missions of each base civil engineering staff.

In the end, the study team chose to have each individual BCE staff nominate applications which it found to be process heat, for whatever reason, with the guidance that the use must be mission related. The study team then excluded uses which were highly seasonal (winter load > 3 times summer load), or highly

impractical (severe site restrictions for a unique application). We considered, but finally excluded very high temperature applications which utilize electric resistance heat. Given the need for a conventional back-up or storage system, these applications are best treated as solar electric applications. Since all such applications which we found, were grid connected, there was no inherent justification for special treatment of these limited applications.

Figure 2-5 presents the applications which were identified, by base. Given the limitations of the data base and the variations in reliability due to different BCE approaches and abilities, the information in the tables should not be taken as definitive. It is also likely that certain specific applications have been overlooked. This data base, therefore, should not be taken as more than a tentative basis for specific system evaluation.

The data base is extremely valuable, on the other hand, as a basis for generic application analysis which is the goal of this research. As far as we know, it is unique. Until a more rigorous data base can be assembled from actual data and an integrated reporting system, this information should be of value to analysts.

It should be noted that several of the identified applications are competing uses. This is the case where process heat systems are served by central steam plants. In these cases, USAF is faced with two strategies. Solar thermal systems may be used to displace fuel by direct insertion of steam into the existing distribution system. Or systems may be designed to meet individual end-use loads with the central steam plant serving as a back-up for hours of non-insolation.

There is a trade-off involved here which is modeled, in part, in section 3. Solar energy systems are most efficient when temperature is matched to the load. Most USAF process heat end uses are low temperature ($\leq 180^{o}F.$). Most USAF steam plants are high temperature ($300\text{-}350^{o}F$). By using solar energy systems at the load, first cost of the energy system can be minimized. Because the current heat exchange system is engineered for $300\text{-}350^{o}$ steam, however, this may require additional capital investment in new heat exchange equipment. Moreover, at some locations space is limited at the process site, although land may exist along the site of distribution lines.

When the steam insertion option is chosen, the first cost of solar equipment will typically increase, but maximum use may be made of the existing capital investment in a conventional system for solar back up. The optimum choice will be site dependent.

The site dependence of solar thermal systems has been referred to before. Obviously, each Air Force Base has a unique

TINKER AFB - APPLICATIONS I

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Miscellaneous - Area A							
Degreaser (210)	260	.20	8	5	-	NG	.400
Cleaning (210)	150	?	8	5	-	NG	?
Rinse (210)	150	?	8	5	-	NG	?
Plexiglass Dry (230)	140-210	?	24	5	-	NG	?
Parachute Drying (229)	120	.35max.	3	5	-	NG	.270
Bearing Degrease (201)	135	.002	8	5	-	E	.003
IPO Expansion (416)	250	.05	8	5	-	E	.10
AREA B							
Manifold Cleaning (3001)							
Degreaser	260	.20	16	5	-	NG	.80
Cleaning Tanks (4)	140-190	?	16	5	-	NG	?
Hot Water Flush	190	.14	16	5	-	NG	.58

Figure 2-5a

TINKER AFB - APPLICATIONS II

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Area B							
Electrical Accessory Cleaning (3001)							
Degreaser	260	.40	8	5	-	NG	.80
Rinse Tank	150	.34	8	5	-	NG	.71
Acid Tank	200	.15	8	5	-	NG	.31
Alkali Tank	120	.07	8	5	-	NG	.15
Degreaser	260	.20	24	5	-	NG	1.20
Degreaser	260	.20	8	5	-	NG	.40
Bearing Shop (3001)							
Degreaser	165	.18	8	5	-	NG	.37
Hot Oil	238	.22	8	5	-	NG	.46
Hot Water	180	.15	8	5	-	NG	.31
Soapy Water	135	.11	8	5	-	NG	.23
Air Driers (3)	238	.01	8	5	-	NG	.02

Figure 2-5b

TINKER AFB - APPLICATIONS III

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Area B							
Tank & Cool (3001)							
Degreaser	260	.20	8	5	-	NG	.40
Clean (2)	140	?	8	5	-	NG	?
Plating Shop (3001)							
Low temp	95-140	2.3	24	5	-	NG	14
Med temp	160-185	2.8	24	5	-	NG	17
Hi temp	190-250	.6	24	5	-	NG	3.7
Total	-	5.7	24	5	-	NG	35
Chemical Clean (3001)	<250 180 avg.	7.8	24	5	-	NG	49
Miscellaneous (3001)							
Degreaser	260	.20	3	5	-	NG	.15
Prying Oven	160	.16	16	5	-	NG	.67
Weld Leaktest (3)	180	.62	24	6	-	NG	4.6
In Process Ovens	160	.16	16	5	-	NG	.67
In Process Clean	180	2.5	8	5	-	NG	5.2
In Process Degrease	170	.20	16	5	-	NG	.16
In Process Steam Clean	320	?	8	5	-	NG	?
Degrease & Still	250	.41	24	5	-	NG	2.6

Figure 2-5c

TINKER AFB - APPLICATIONS IV

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Area B							
Heat Treat (3001)							
Clean	120	.034	16	5	-	NG	.053
Degrease	250	.29	24	5	-	NG	..37
Building 3105							
Degrease	250	.41	16	5	-	NG	1.7
Clean	130	.26	16	5	-	NG	1.1
Building 2101							
Tube Clean	<200	.45	8	5	-	NG	.94
Building 2210							
Degrease (2)	260	.20	16	5	-	NG	.80
Chem. Tank	190	?	16	5	-	NG	?
Rinse Tank	190	?	16	5	-	NG	?
Vehicle Wash Rack (3123)	140	.01	.5	5	-	NG	.001
Central Plant	350	67-125	24	7	S,W	NG	860
Make Up	180-200	6-10	24	7	S,W	NG	60

Figure 2-5d

EGLIN AFB - APPLICATIONS

Application	T(^{O}F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Laundry (876)	350	Min. 4.9 Avg. 5.9	8	5	-	NG	12
Make Up	180-200	Min. .13 Avg. .19	8	5	-	NG	.4
Water Only	190	2.9	8	5	-	NG	5.8
Hospital (2825)	300	Min. 2.5 Avg. 3.3	24	7	-	NG	29
Make Up	-	-	-	-	-	NG	-
Corrosion Control (72)	75 (250)	3.4max.	0-24	0-7	N	NG	3(E)
Parachute Drying (32)	80 (250)	< .5 (cap)	24	2-4	Rain +S	NG	1.8(E)

Figure 2-5e

LOWRY AFB - APPLICATIONS

Application	T(^{o}F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^{9} BTU)
Space Conditioning							
Intel School (379)	250±	$\overline{1.8}$-$\overline{3.9}$	8	5	W	NG	12(E)
Dormitory (400)	250±	$\overline{1.9}$-$\overline{9.1}$	24	7	W	NG	48(E)
School Building (1307)	250±	$\overline{2.3}$-$\overline{5.9}$	8	5	W	NG	17(E)
Barracks (1477)	250±	$\overline{2.0}$-$\overline{13.8}$	24	7	W	NG	69(E)
Clipper (444)	180	2(E)	5	6	-	NG	3(E)
Central Steam Plant (361)	350	$\overline{20}$	24	7	W	NG (O)(C)	170
Make Up	200	$\overline{3.4}$	24	7	W	NG (O)(C)	30

Figure 2-5f

MACDILL AFB - APPLICATIONS

Application	T(^{O}F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Space Conditioning (Reheat)							
F-16 Avionics (6)	190	.054	24	7	-	O	.5
Flight Simulator (36)	190(E)	.03	24	7	-	E	.3
Telephone Exchange (40)	190(E)	.07	24	7	-	E	.6
PMEL (42)	190(E)	.12	24	7	-	E	1.0
Fuel Lab (1121)	190(E)	.22	24	7	-	O	1.9
Hospital (711/712)	350	$\overline{3.4}$min. $\overline{5.5}$avg.	24	7	S,S,F	C	.48
Make Up	200$\pm$	$\overline{.06}$avg.	24	7	S	O	.47
Corrosion Control (1005)	70+	$\overline{.15}$max.	varies		W	NG	?

Figure 2-5g

ROBINS AFB - APPLICATIONS

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Cleaning Tanks (169)	≤ 190	<1.4	24	5	-	NG 83% (0)	<12
Plating Shop (142)	≤ 190	<6.5	24	5	-	NG 83% (0)	<57
Space Conditioning							
Gyro Shop (158,160)	(325)	<1.4	24	7	-	NG 83% (0)	<7
Avionics (640)	(300)	<4.9	24	7		NG 90% (0)	<25
Avionics (645)	(300)	<9.0	24	7		NG 90% (0)	<45
Paint Hangar (89)	≤ 190	<10.8	8	5	-	NG 83% 0-	UNIC
Central Plant (177)	325	min 25 max 175 avg 80	24	7	W	NG 83% (0)	700
Make Up	180-200	2-4	24	7	W	NG 83% (0)	20
Central Plant (644)	300	min 8 max 37 avg 16	24	7	W	NG 90% 0	170
Make Up	180-200	.5-1.0	24	7	W	NG 90% 0	5

Figure 2-5h

MARCH AFB - APPLICATIONS

Application	T(°F)	Heat Rate (MBTU/Hr)	Duty Cycle hrs/d	d/w	S	Fuel	Annual Use (10^9 BTU)
Hospital (2990)	300	3-6	24	7	S.W	NG (O)	40(E)

Figure 2-5i

combination of factors which will determine specific application feasibility. Yet, some general patterns emerged from our six site visits which bear reporting here. Figure 2-6 presents these observations.

In general, USAF bases have good site resources. There is usually empty land available, and often large, unused roof space. Occasionally runway height restrictions prohibit use of a specific roof or land area, but this is not generally a problem. More commonly, there is a mismatch between the location of the application and that of available land.

The working areas of AFBs tend to be densely built up over an area relatively small to land resources. Other areas lie vacant. This is especially noticeable at a base such as Eglin AFB which has literally square miles of unused land and a dense central base area. In part this phenomenon is due to the need for access to taxiways so that aircraft can be brought up to the work areas. In part is is due to the existence of central heat plants and the consequent clustering of heat uses to minimize heat transport distances. For new facilities construction, distributed energy systems may provide opportunities to decrease congestion.

For retrofit energy plants, peripheral location with heat transport, often using existing steam or condensate lines for part or all of the distribution, is one option. The other is roof mounting. (Note: Some bases have land available next to application sites now.) Many bases have vast and adequate roof spaces at application sites. However, roof load capabilities were not immediately available at any site for which they were sought. The actual feasibility of roof mounting will have to be determined for each specific site.

Two special questions have to be resolved for most USAF applications. The possibility of reflected light from collectors being a nuisance or hazard to flight operations has not been rigorously assessed, although the operation of flat plate collectors at Robins AFB and of the power tower at Kirtland AFB indicate this may not be a problem. The question of solar ponds attracting water fowl has been raised but as of this date not definitely answered. We assume that the high salt concentrations and temperature gradients would not be an attractive environment, but no one has yet positively verified this assumption.

USAF IPH SITES

- A GENERAL PATTERN: DENSELY BUILT-UP CENTRAL AREA, ADJACENT TO RUNWAY, AND A LARGE, SPARSELY UTILIZED PERIPHERY.
- CENTRAL STEAM PLANTS SERVE CENTRAL WORK AREA. LINES EXTEND TO PARTS OF 'ERIPHERY. SMALL BOILERS SERVE REMOTE NEEDS, USUALLY SPACE CONDITIONING.
- LAND AREA SCARCE AT CENTER. ROOF AREA TYPICALLY PLENTIFUL
 - ROOF LOAD TOLERANCES GENERALLY UNKNOWN
 - HEIGHT RESTRICTIONS MAY EXIST, NOT A GENERAL BARRIER
- PERIPHERAL LAND OFTEN AVAILABLE, BUT FAR FROM APPLICATIONS
 - CONDENSATE RETURN AND STEAM LINES MAY EXIST
- UNKNOWN FACTORS
 - GLARE FROM MIRRORS?
 - BIRDS AND PONDS?

Figure 2-6

d. The Generic Applications

Given the types and nature of data available, Applied Concepts selected for the analysis of solar thermal systems in USAF applications an end use matching methodology which has been developed by SERI. This was the first utilization of this state-of-the-art computer model by an agency external to SERI. The help and interest of the staff of SERI's Industrial Applications and Policy Branch was invaluable in the performance of the evaluation. The model is described in Section 3, below.

For input to the model, it was necessary to design a special, generic application data base to represent USAF applications at different locations. Accordingly, the project team defined the generic applications presented in Figure 2-7. These were selected to generically incorporate the range of observed USAF applications.

The first group of two represent water preheat applications. They can also stand for water heating where there is no waste water return. These applications are identified by the prefix 100, i.e. 101, 102, in later tables. The last group of two (401, 402) represent indirect hot water conversion. The lower efficiency of fuel utilization was selected to represent transmission and heat exchange losses in a central steam back-up system.

The largest group of applications (201-212) represent steam insertion at various quantified output temperatures into an existing central boiler distribution system. The remaining group (301-304) represents the utilization of process steam at the point of application in various quantifies, with and without condensate return.

Figure 2-8 graphically depicts the relationship between the observed applications and the generic application set. The empty sets (203, 9; 204, 10; and 206, 12) represent temperature ranges which were not observed at the six bases visited, but which may be likely variants at other locations.

e. General Findings

Figure 2-9 presents a summary chart of USAF applications as determined during the six site visits. The generic data base presented in figure 2-7 is the major input to the applications/ technology comparison which is the objective of the generic analysis task. The extensive information gathered on specific applications at the six bases visited will be valuable in Task 2, forming one basis for the selection of five specific applications for case study.

THE SPECIAL DATA BASE:
GENERIC APPLICATIONS
FOR COMPUTER ANALYSIS

Application/System \ Characteristics		Process Temp.(°F)	Inlet Temp.(°F)	Outlet Temp.(°F)	Process Heat Rate (MilBTU/Hr.)	Fuel Utilization Efficiency
Boiler Feedwater Preheat	1.	180	55	190	6	.80
(Hot water direct) (100)	2.	200	55	210	6	.80
	1.	250	55	250	10	.75
	2.	350	55	350	10	.75
	3.	400	55	400	10	.75
	4.	250	200	250	10	.75
Steam Generation	5.	350	200	350	10	.75
and Insertion	6.	400	200	400	10	.75
(Steam Flash) (200)	7.	250	55	250	1	.75
	8.	350	55	350	1	.75
	9.	400	55	400	1	.75
	10.	250	200	250	1	.75
	11.	350	200	350	1	.75
	12.	400	200	400	1	.75
Process Direct	1.	250	55	270	.2	.60
Supplement	2.	250	200	270	.2	.60
(Steam Indirect) (300)	3.	250	55	270	.5	.60
	4.	250	200	270	.5	.60
Hot Water Conversion	1.	200	220	250	5	.60
(Hot Water Indirect) (400)	2.	200	220	250	1	.60

Figure 2-7

DISTRIBUTION OF GENERAL APPLICATIONS

	EGLIN	ROBINS	TINKER	MACDILL	LOWRY	MARCH
101 OR 102	2/6.2	2/25	1/60	1/.5	1/30	
201,7					3/77	
202,8			1/0.1		1/69	
203,9						
204,10						
205,11	2/35	3/985	1/860	1/48		1/40
206,12						
301	1/0.4		9/5			
302			2/1			
303			4/8.8			
304						
401	1/3	1+(1)/57+(?)	3+/85+			
402	1/2	1/12	12/10	1/4.3		

NUMBER / 10⁶ BTU/YEAR CURRENT USEAGE

Figure 2-8

USAF APPLICATIONS
OVERVIEW

	EGLIN	ROBINS	TINKER	MACDILL	LOWRY	MARCH	TEMPERATURE RANGE (°F)	SIZE RANGE (BTU/YR. 10^6)
CENTRAL PLANT		✓	✓		✓		300-350	170-860
HOSPITAL	✓			✓		✓	300-350	29-48
INDUSTRIAL SOLVENTS		✓	✓				140-190 200-260	.01-17 .4-4
CORROSION CONTROL	✓	✓	✓	✓			70-180	?
PARACHUTE DRYING	✓		✓	(✓)			80	.3-1.8
ENVIRONMENTAL CONTROL	✓	✓	✓	✓	✓	✓	80-(350)	7-70
LAUNDRY	✓						350	12

Figure 2-9

The major findings of this task, therefore, are transitive, the inputs to further work. However, it is important to make USAF aware of the collateral findings regarding the availability of data for further assessments of renewable energy systems, and of the inplications for energy program management which the current situation poses.

The essence of the situation is this: Because current, headquarters' level data and reporting has evolved to meet the needs of a centralized and fossil fuel utilization perspective, there exists no headquarters' level information system which can be directly utilized to analyze process heat applications for solar energy systems. The lack of an appropriate information base limits headquarters' abilities to assess the feasibility of new technologies. It also tends to inhibit new or creative approaches to energy conservation. Even EMCS programs, as currently structured, are primarily designed to improve upon the status quo, without yielding information which is applicable to assessing alternative solutions to conservation problems.

There does exist a large amount of information at the base civil engineering and user level. There is, however, a great variation among bases and among applications as to the quality and quantity of this information. It is sometimes difficult to assess the reliability of the data which does exist.

Much of the information which is available is in the form of estimates or special studies. It is ad hoc in its availability. It is not the result of institutionalized planning. There is clearly a gap between the information needed for solar energy planning and the information which is readily available to USAF decision makers and planners.

The quantity of information, and the site specificity required for solar assessment thus impose different requirements on energy information management than did conventional technologies. These requirements are similar to those imposed by other renewable energy systems and by conservation planning. To address the mismatch between the planning function and the availability of information, either massive amounts of information must be transferred to the headquarters' or planning levels or certain planning functions must be transferred to the base level.

The major barrier on the local base level to accurate analysis is the general lack of empirical, measured data on energy consumption. For further assessments and for specific application analyses, hard, historical data is desirable on process fuel consumption, heat production and heat losses to permit energy and mass balance equations. The USAF metering program, which has heretofore concentrated on metering buildings or boilers only, needs to be reconsidered to help yield this information for planning.

3. Technology/Applications Assessment

a. Overview

SERI's PROSYS/ECONMAT model was selected as the analytical tool to assess alternative solar process heat technologies in the generic applications. This model was selected by the project team because, of all such models of which we are aware, it best meets the following criteria:

- Available to outside users
- State-of-the-art
- Comparability of results
- Flexible - Capable of performing generic end-use matching as well as detailed case studies
- Includes most solar thermal technologies
- Covers all of CONUS

The PROSYS/ECONMAT model has two basic parts--PROSYS and ECONMAT. PROSYS predicts solar system performance in meeting process temperature and heat rate requirements at a specific site. ECONMAT evaluates the economic attractiveness of solar process heat in the specified applications. The model provides for extensive user input, thus allowing a customized analysis. Prespecified default values for most input parameters are also provided. The default values are reasonable, benchmark estimates based upon SERI's long experience in analyzing solar process heat systems as well as results of DOE-supported field tests. The model has extensive built-in data bases, including:

- Insolation data on 231 sites in the U.S.
- Performance and cost data on 16 commercially available systems
- State average labor rates and fuel prices
- Cost factors for auxiliary and interface materials and labor

PROSYS/ECONMAT utilizes the Rabl and Collares-Pereira approach to calculate the energy delivered to the process by the solar system, and the Dickenson-Brown approach for the economic analysis. It provides for a "transparent" analysis--incremental output of subroutines and various model segments is available to

the user. Most importantly for this study, PROSYS/ECONMAT provides a uniform comparison of alternative systems and applications, at alternative sites.

The model does have some limitations which should be kept in mind when interpreting the results. All solar systems are sized to meet the minimum average hourly process load. The solar system's peak output will just equal the application's minimum process load. Thus, all energy produced by the solar system during the process duty cycle is assumed to be used. Also, 100% conventional fuel backup is assumed--there is no consideration of storage. Collector operating temperature is assumed to be constant. The models can be used for flat plates, evacuated tubes, parabolic dishes, and parabolic troughs, but not for solar ponds or power towers. Solar ponds were analyzed separately by the project team (the results are presented later in this report) based on technical and cost data provided by JPL. System components and costs are not explicitly modeled. Rather, the model uses efficiency factors and cost coefficients to estimate the costs of auxiliary collector materials, interface materials and labor, freight, construction overhead, and other miscellaneous costs. While the PROSYS/ECONMAT model is an attractive feasibility analysis tool, it is too generalized, even with extensive user input, to be used as a detailed design tool. Finally, the reader should be aware that, although the basic PROSYS and ECONMAT estimation algorithms have been previously published and widely used, its output has not been compared with other such models outside SERI.

In order to run PROSYS/ECONMAT, the user must first characterize the applications to be analyzed and identify the site or sites at which each is located. Five main application parameters must be specified:

- Temperature
- Heat rate
- Duty cycle
- Fuel type
- Fuel price

The input data on applications used in this analysis was given in Figure 2-2.

The user then specifies the economic scenerio and selects the solar hardware to be analyzed in each application. The user may employ the default values that are stored within the model or overide them with his own values. Figure 3-1 presents the model inputs with the values used in this analysis given in parentheses. Figure 3-2 compares the costs of the different systems that were analyzed. For flat plates and evacuated tubes, the least and most costly systems in the data base were analyzed. For parabolic troughs, the least expensive, most expensive, and a mid-range cost system were analyzed. Reliable cost estimates were available for only one parabolic dish. Model outputs are described in Figure 3-3.

PROSYS/ECONMAT

USER INPUTS

1. Number Days per Week Operation (7)
2. Monthly Operating Schedule (12)
3. Orientation of Parabolic Troughs (N-S)
4. Conventional Fuel Utilization Efficiency (varies)
5. Cutoff Time in Hours from Noon (optimizes for each collector and site)
6. Conventional Fuel Type (natural gas and #2 fuel oil)
7. Conventional Fuel Price (actual)
8. Fuel Price Escalation Rate (.16 for natural gas; .11 for fuel oil)
9. Collector Array Auxiliary Materials Cost Factor (varies by type of collector and application)
10. Collector Array Installation Labor Cost Factor (varies by type of collector and application)
11. Process Interface Materials Cost Factor (varies by type of collector and application)
12. Process Interface Installation Labor Cost Factor (varies by type of collector and application)
13. Engineering Design and Office Costs Factor (.06)
14. Freight Insurance and Property Taxes Factor (.05)
15. Construction Overhead Factor (.5)
16. Contingency Factor (.15)
17. Fee Factor (.06)
18. Discount Rate (.10)
19. General Inflation Rate (.08)

Figure 3-1a

PROSYS/ECONMAT

USER INPUTS

cont'd.

20. Federal Income Tax Rate (0)
21. State Income Tax Rate (0)
22. Federal Solar and Investment Tax Credit (0)
23. State Solar Tax Credit (0)
24. Service Life of the Solar System (20)
25. System Start-up Year (1983)
26. Escalation Rate for Solar System Materials Cost (.05)
27. Escalation Rate for Solar System Labor Cost (.05)
28. Loan Fraction (0)
29. Interest Rate on Loan (0)
30. Loan Period (0)
31. Net Salvage Value as Fraction of Total Investment (0)
32. Depreciation Period (0)
33. Type of Depreciation (none)
34. Component Replacement Cost as Fraction of Initial Investment (.005)
35. Year in which Component is replaced (10)
36. Average Cost of Operation, Maintenance, Property Tax, and Insurance as Fraction of Initial Investment (.02)
37. Land Cost per Acre (0)
38. O&M Labor Rate (State avg.)
39. System Performance Deterioration (0)

Figure 3-1b

COST-COMPARISON OF SYSTEM TYPES AND MANUFACTURERS
$/Sq.Ft.

	Flat Plate B	Flat Plate C	EVAC. Tube A	EVAC. Tube B	Par. Trough A	Par. Trough B	Par. Trough C	Par. Dish
1. Collector F.O.B. Cost	17.00	12.00	22.00	25.00	26.00	23.00	25.00	42.48
2. Aux.Collector Array Mat.	3.23	2.28	4.62	5.25	3.64	3.22	3.50	5.52
3. Tot.Collector Array Mat.	20.23	14.28	26.62	30.25	29.64	26.22	28.50	48.00
4. Process Interface Mat.	.37	.26	.48	.55	.54	.48	.52	.87
5. Tot. Direct Material Cost	20.60	19.54	27.10	30.80	30.18	26.70	29.02	48.87
6. Mat. Escal. to Start Yr.	23.84	16.83	31.38	35.65	34.93	30.90	33.59	56.58
7. Engineering & Office Costs	1.43	1.01	1.88	2.14	2.10	1.85	2.02	3.39
8. Freight and Taxes	1.19	.84	1.57	1.78	1.75	1.55	1.68	2.83
9. Tot.Direct & Indirect Mat.	26.47	18.68	34.83	39.58	38.78	34.30	37.29	62.80
10. Collector Array Install. Labor	2.02	1.43	2.90	3.29	3.77	3.33	3.62	5.66
11. Process Interface Install. Labor	.15	.10	.19	.22	.22	.19	.21	.35
12. Tot.Direct Labor Costs	2.17	1.53	3.09	3.51	3.98	3.52	3.83	6.01
13. Labor Escal. to Start Yr.	2.51	1.77	3.58	4.07	4.61	4.08	4.43	6.96
14. Construction Overhead	1.25	.88	1.79	2.03	2.30	2.04	2.22	3.48
15. Tot.Direct & Ind. Labor	3.76	2.65	5.37	6.10	6.91	6.11	6.65	10.44
16. Tot.Direct & Ind. Costs	30.23	21.34	40.20	45.68	45.69	40.42	43.93	73.24
17. Contingency	4.53	3.20	6.03	6.85	6.85	6.06	6.59	10.99
18. Fee	2.09	1.47	2.77	3.15	3.15	2.79	3.03	5.05
19. Total Solar System Cost	36.85	26.01	49.00	55.68	55.70	49.27	53.55	89.28

Figure 3-2

PROSYS/ECONMAT OUTPUTS

FOR EACH SITE, APPLICATION, AND SYSTEM COMBINATION:

- DELIVERED ENERGY (MILBTU/YR)
- COLLECTOR SIZE (SQ. FT.)
- AREA REQUIRED (ACRES)
- TOTAL INVESTMENT ($)
- DETAILED SOLAR SYSTEM COST ESTIMATES ($/SQ. FT.)
- ANNUAL ENERGY CAPACITY COST ($/MILBTU/YR)
- NET PRESENT VALUE ($)
- DISCOUNTED PAYBACK PERIOD (YRS.)
- UNDISCOUNTED PAYBACK PERIOD (YRS.)
- INTERNAL RATE OF RETURN (%)

Figure 3-3

b. Findings

Figures 3-4 and 3-5 summarize the findings from all the bases. For each base, the system with the highest return on investment (R.O.I.) has been selected for each application. The reader is cautioned that R.O.I. is undiscounted and thus represents the discount rate at which the net present value would be equal to zero. From these figures it becomes evident that return on investment is generally highest at those bases with the most favorable solar climate. Kirtland, McClellan, March, and Hill are among the most attractive bases regardless of whether the backup fuel is natural gas or fuel oil. This is so even though natural gas prices vary considerably across these bases (from $2.86/MilBtu at Hill to $4.34/MilBtu at Kirtland.

Nevertheless, return on investment is very sensitive to differences in fuel costs. With natural gas backup, which varies substantially in price across bases, the difference in R.O.I. across bases is much greater than with fuel oil, whose price varies little across USAF bases. The case of MacDill offers a good example of the importance of backup fuel prices. It has only a moderately attractive solar climate but the highest natural gas price of any base analyzed. It ranks third in attractiveness for mid-temperature applications and second for low temperature applications. The MacDill example also illustrates the finding that a base may have a greater relative "advantage" in either direct normal or total radiation. Figure 3-6 compares insolation and fuel prices at the 10 bases analyzed.

Figures 3-4 and 3-5 also show that, regardless of the base or backup fuel, low temperature applications (101 and 102) offer substantially higher return on investment than mid-temperature applications. The reader should keep in mind, however, that due to ongoing R&D, the near-term potential for further increases in return on investment is with mid-temperature applications. The reader is also cautioned that, due to the compounding effect, small differences in percentage return on investment can translate into very large dollar differences.

Figures 3-7 and 3-8 summarize for Tinker the R.O.I. of different types of systems produced by different manufacturers As expected, flat plates and evacuated tubes tend to be relatively more attractive for low temperature applications, and troughs and dishes tend to be more attractive for mid-temperature applications. Flat plates show a clear advantage over all other systems for boiler feedwater preheat. Dishes and troughs offer higher R.O.I. over more applications, however. The highest ranked parabolic trough is consistently the best system at current production prices. The only parabolic dish for which reliable cost and performance values were available ranked above other troughs, even though prototype prices were used.

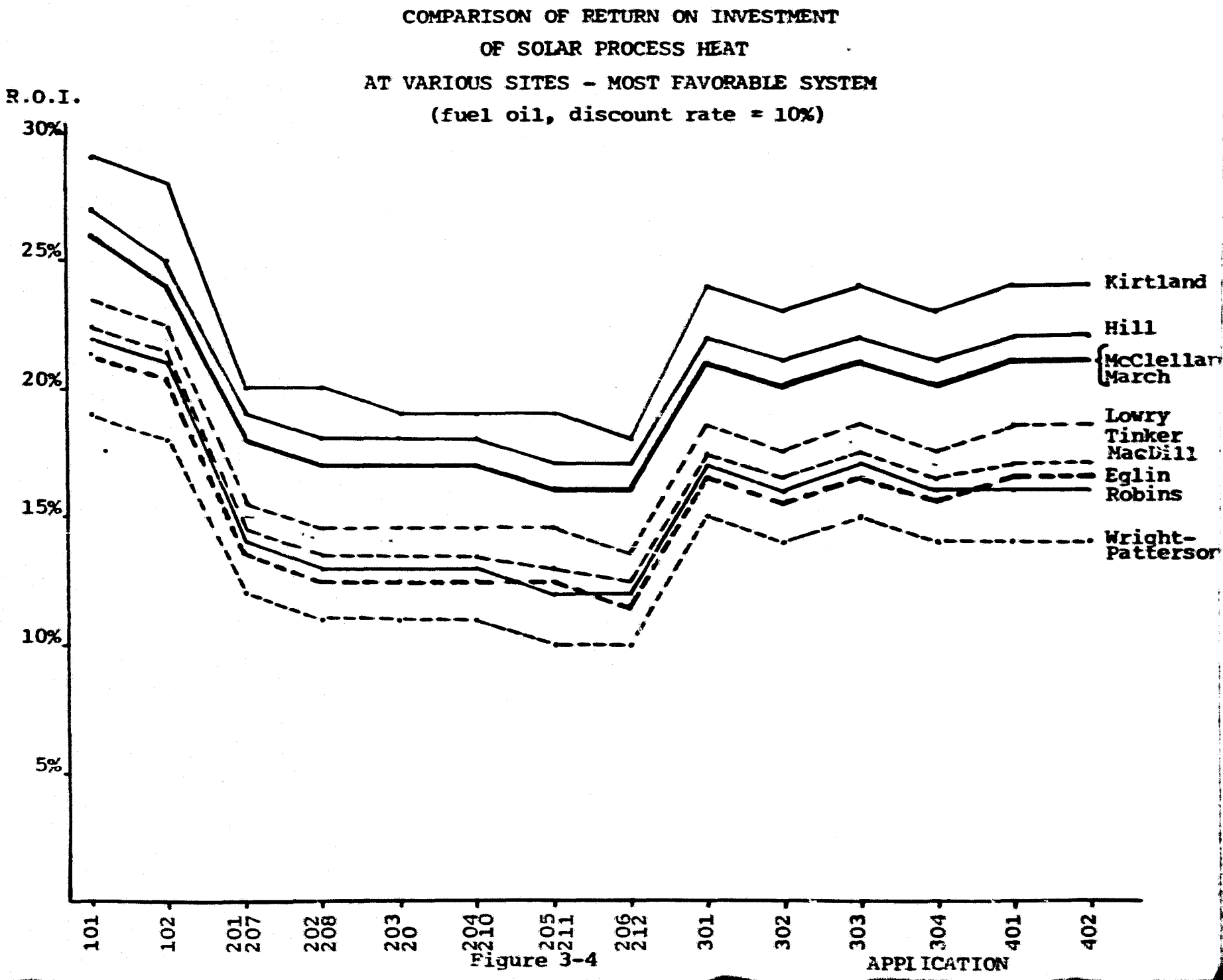

COMPARISON OF RETURN ON INVESTMENT
OF SOLAR PROCESS HEAT
AT VARIOUS SITES - MOST FAVORABLE SYSTEM
(fuel oil, discount rate = 10%)
R.O.I.
30%
25%
20%
15%
10%
5%
Kirtland
Hill
McClellan
March
Lowry
Tinker
MacDill
Eglin
Robins
Wright-
Patterson
101
102
201
207
202
208
203
20
204
210
205
211
206
212
301
302
303
304
401
402
APPLICATION

Figure 3-4

COMPARISON OF RETURN ON INVESTMENT
OF SOLAR PROCESS HEAT
AT VARIOUS SITES - MOST FAVORABLE SYSTEMS
(Natural Gas, discount rate = 10%)

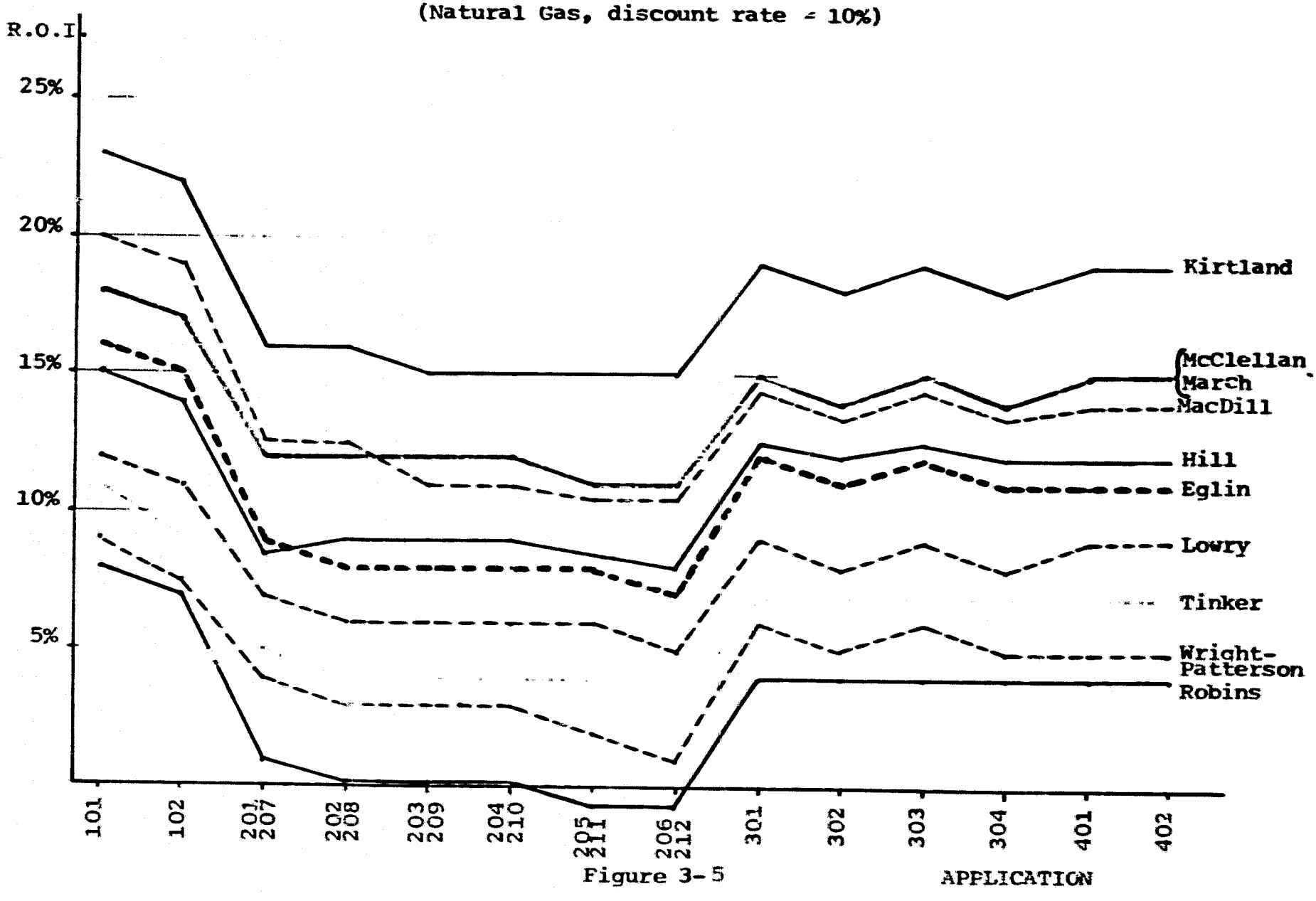


Figure 3-5

COMPARISON OF INSOLATION AND FUEL PRICES

AT THE VARIOUS SITES

Base	Avg. Daily Solar Radiation on a Horizontal Surface (BTU/sq.ft.)	Avg. Daily Direct Normal Solar Radiation (BTU/sq.ft.)	Natural Gas Price ($/Mil BTU)	Fuel Oil Price ($/Mil BTU)
Kirtland	1762	2291	$4.34*	$8.796**
Hill	1674	2114	$2.86	$8.796
McClellan	1674	1762	$3.78	$8.796
March	1586	1762	$3.10	$8.796**
Lowry	1674	2026	$2.37	$7.06
Tinker	1498	1586	$2.315	$8.796
MacDill	1498	1322	$4.44	$8.25
Eglin	1410	1322	$3.48	$8.796
Robins	1233	1410	$1.97	$8.796
Wright-Patterson	969	1145	$2.95	$10.02

* = state average price to industrial customers

** = assumed to be equal to common USAF-wide cost of $1.22/gallon

Figure 3-8

RETURN ON INVESTMENT OF ALTERNATIVE SYSTEMS

AT TINKER AFB

(fuel oil, discount rate = 10%)

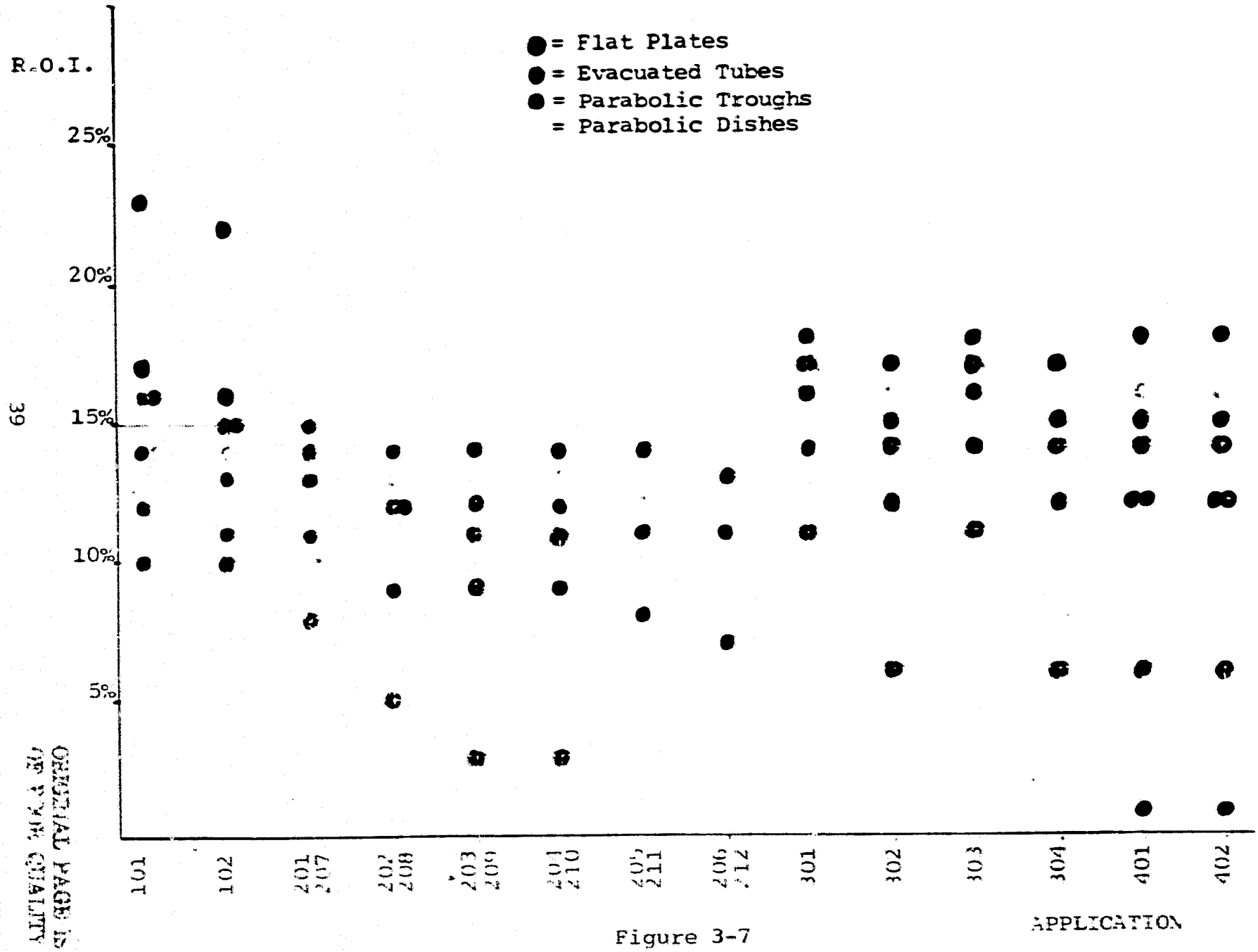


Figure 3-7

RETURN ON INVESTMENT OF ALTERNATIVE SYSTEMS

AT TINKER AFB

(Natural Gas, discount rate = 10%)

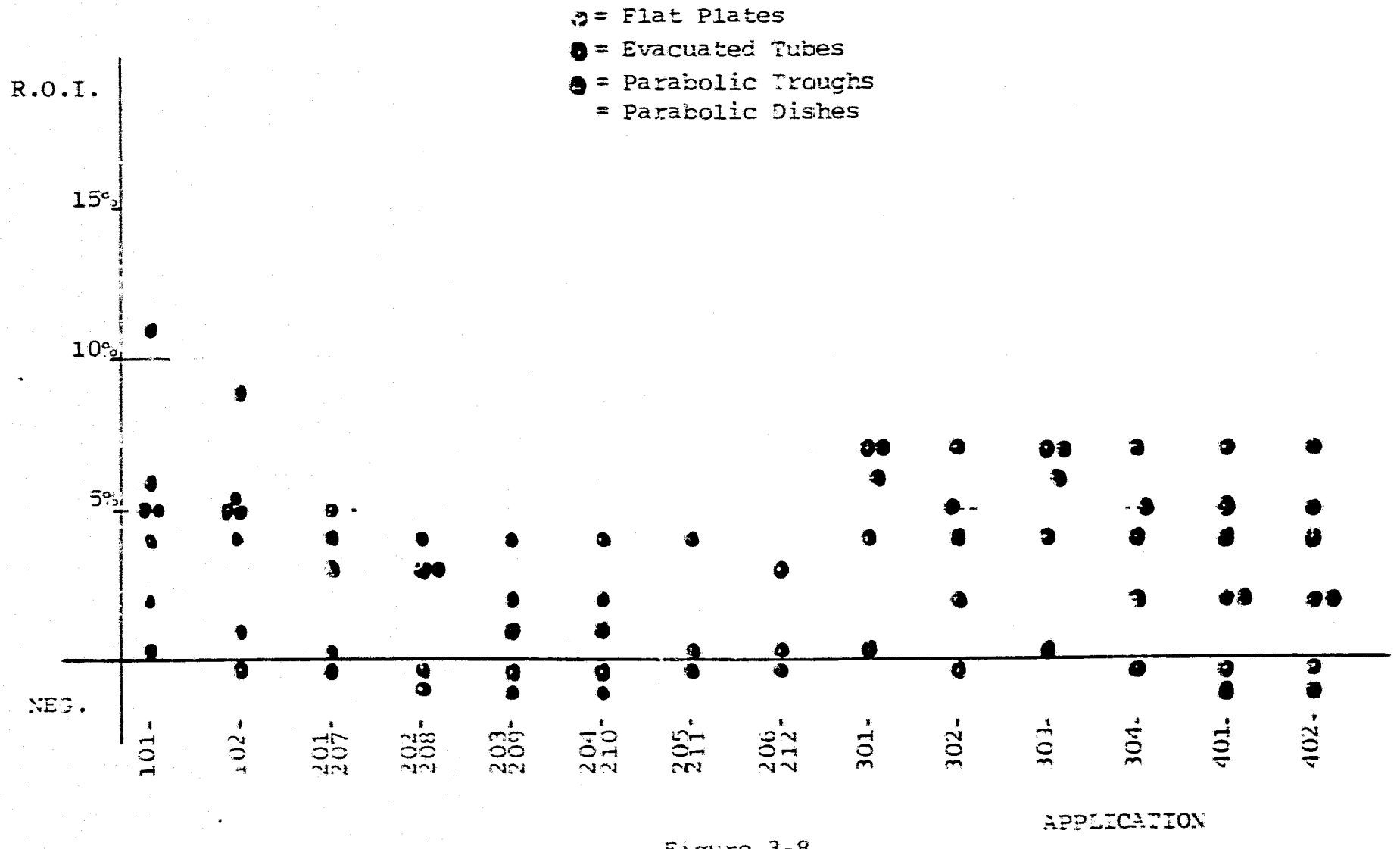


Figure 3-8

It was also found that R.O.I. estimates vary significantly by technology and manufacturer. This is due to different costs and efficiencies of the different systems. We believe this is a key finding of the research, and points out the necessity for USAF to closely assess any system/application configuration before making a purchase decision. It also means that even if USAF should decide to select one technology for widespread use, it must still take great care in selecting the manufacturer(s). The previous caveat regarding systems costs is repeated here. Systems costs used in the analysis are based upon currently quoted prices of systems which have been fielded. This "penalizes" systems just entering the marketplace which may be able to significantly reduce costs in the future. For example, the project team was recently informed that in lot sizes of 500 or more the parabolic dish which was analyzed would sell for less than half the price used in the analysis. This would almost certainly make it the top ranked system for mid-temperature applications. The lesson for USAF is clear. It must continue to track the development and costs of solar process heat hardware if it is to make informed investment decisions in this area.

It was also found that solar process heat is almost twice as attractive to USAF as opposed to private firms. The factors which tend to make solar systems more attractive to private firms, such as depreciation and solar and investment tax credits, are more than offset by the fact that private firms expense fossil fuel costs. They effectively pass on (to government) a percentage of the cost equal to their effective combined federal and state marginal tax rate. Figure 3-9 presents a comparison of project net present value at Tinker AFB and a private firm in Oklahoma City with identical fuel oil costs. R.O.I. would also be substantially higher for USAF than the private firm.

While the overall economic attractiveness of solar systems is much greater for USAF than private firms, USAF's payback period is longer. Private firms accelerate their return on investment by taking tax credits immediately, by depreciating the solar system over 7 years, and by using accelerated depreciation. Figure 3-10 depicts payback periods under the same scenerio as Figure 3-9. Figure 3-11 compares conceptually the flow of savings from a solar energy investment for USAF and a private firm.

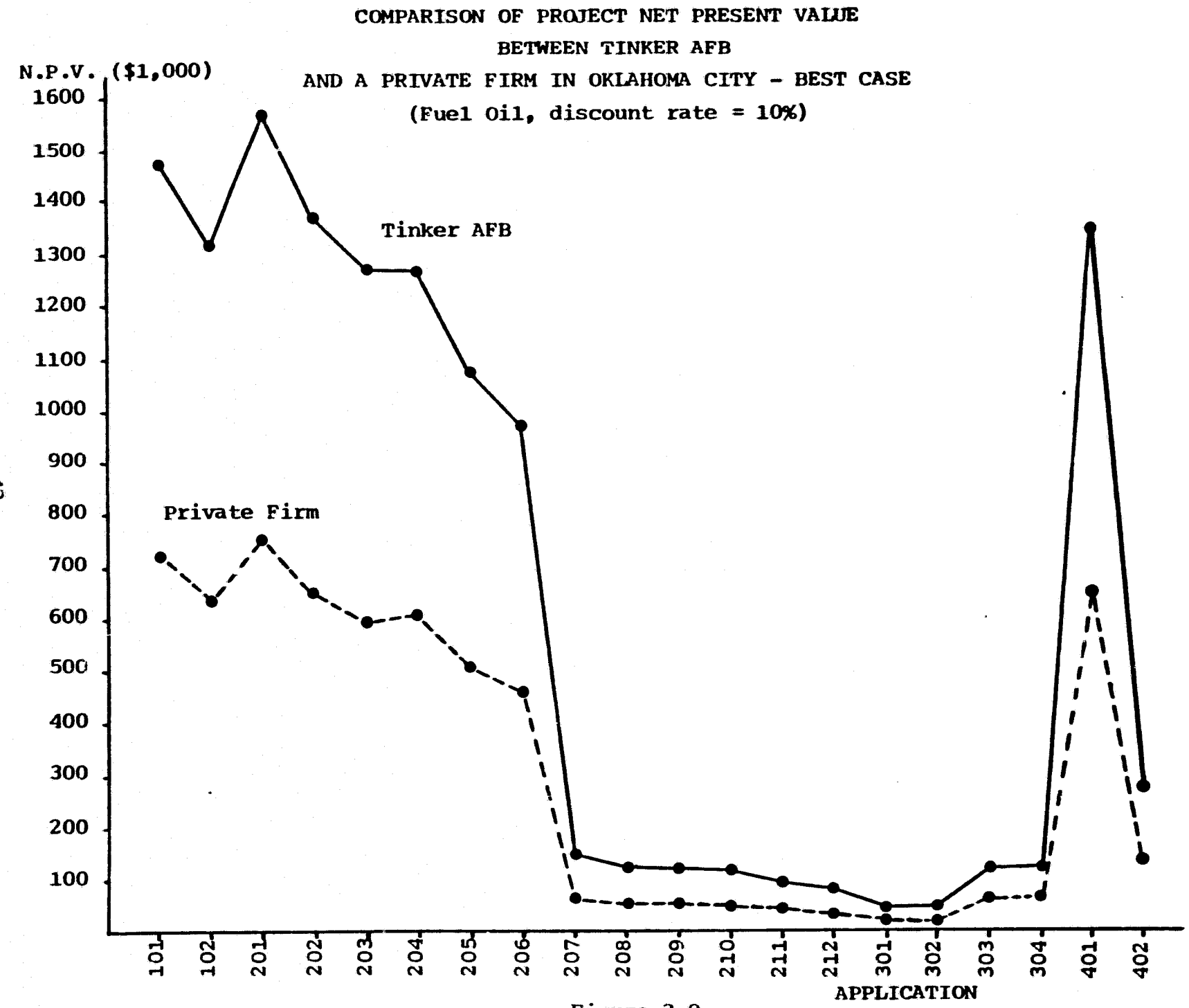

COMPARISON OF PROJECT NET PRESENT VALUE
BETWEEN TINKER AFB
AND A PRIVATE FIRM IN OKLAHOMA CITY - BEST CASE
(Fuel Oil, discount rate = 10%)
N.P.V. ($1,000)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Tinker AFB
Private Firm
101
102
201
202
203
204
205
206
207
208
209
210
211
212
301
302
303
304
401
402
APPLICATION

Figure 3-9

COMPARISON OF PAYBACK PERIOD
OF TINKER AFB AND A PRIVATE FIRM IN OKLAHOMA CITY
- BEST CASE
(Fuel Oil, discount rate = 10%)

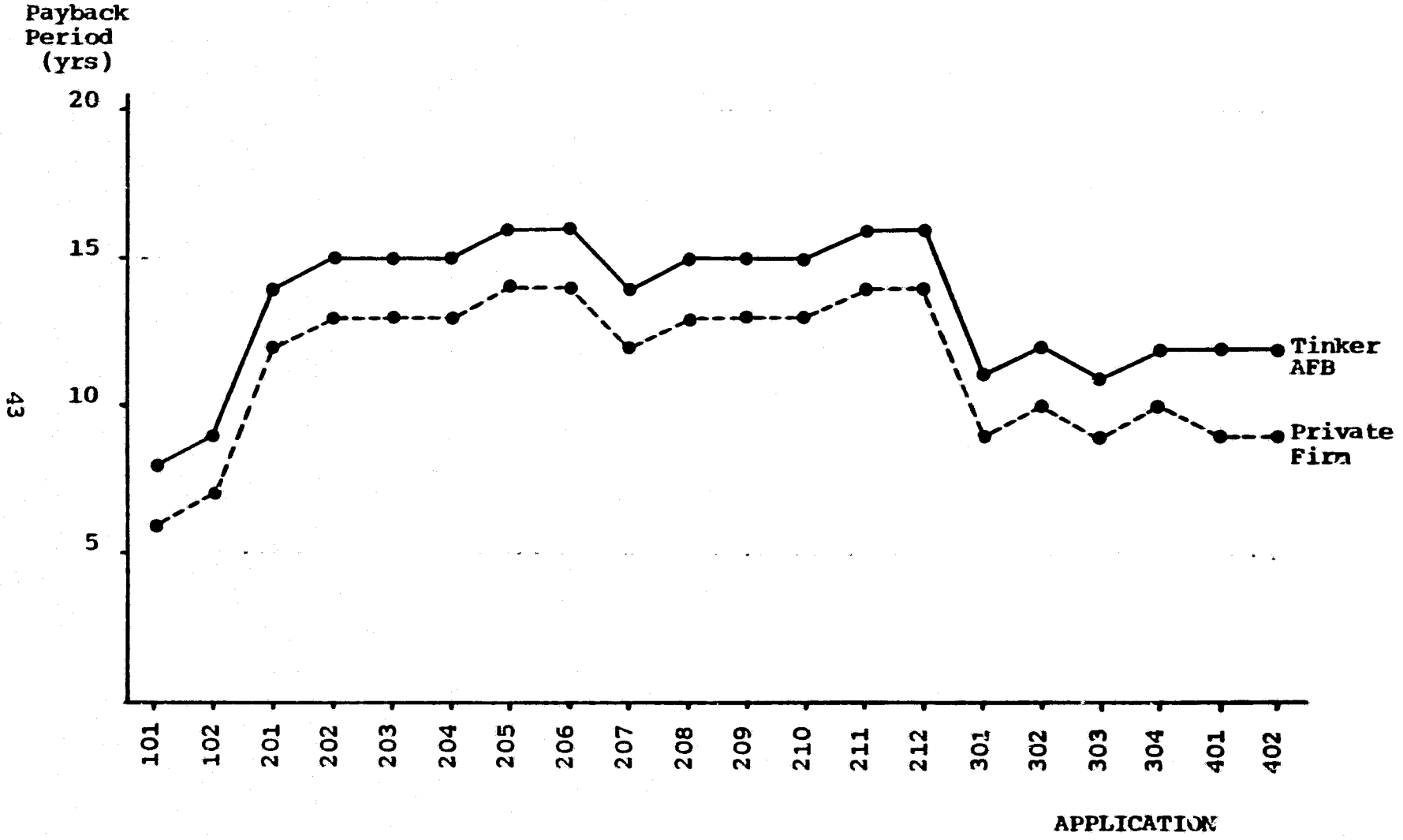


Figure 3-10

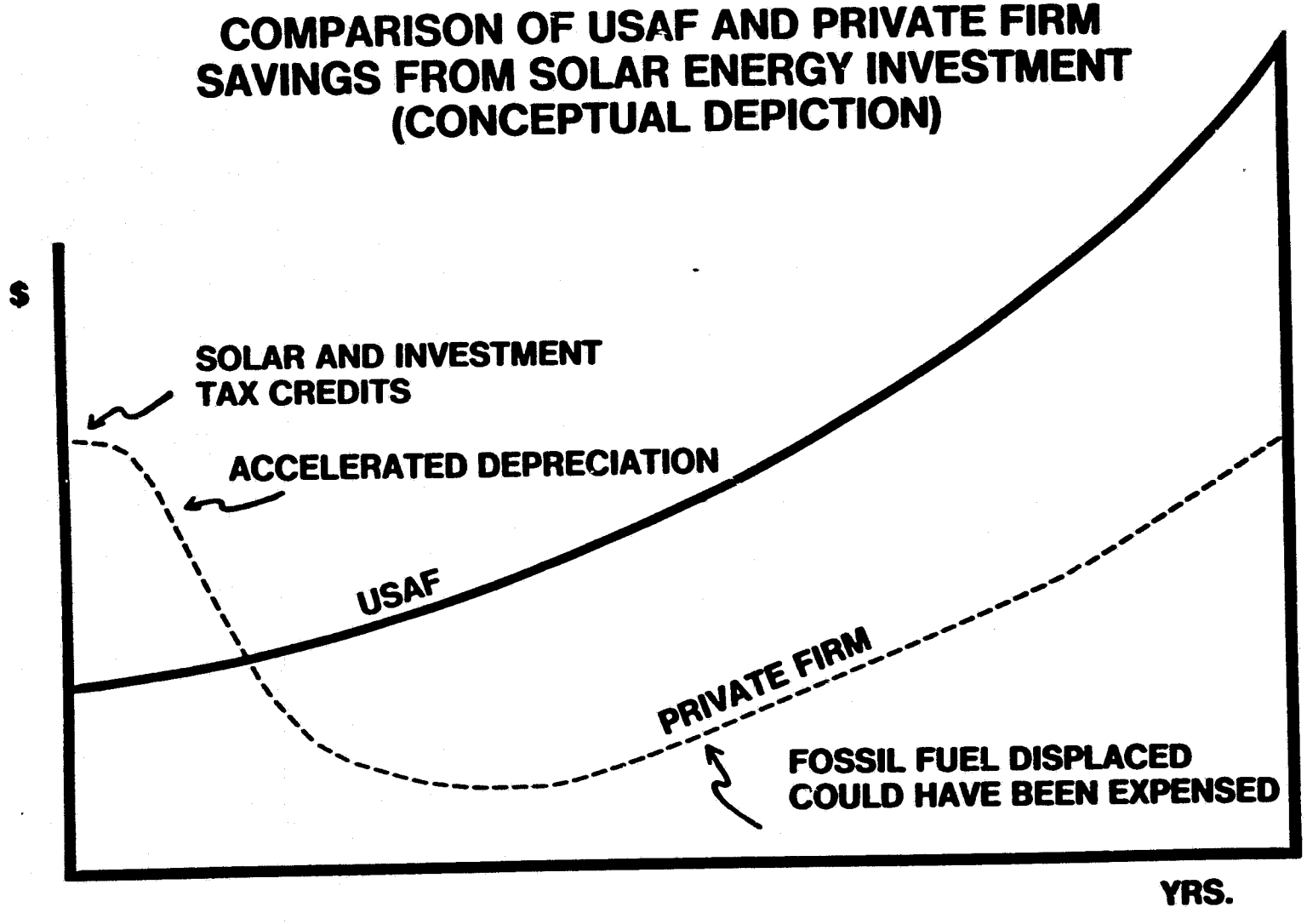

COMPARISON OF USAF AND PRIVATE FIRM
SAVINGS FROM SOLAR ENERGY INVESTMENT
(CONCEPTUAL DEPICTION)
$
SOLAR AND INVESTMENT
TAX CREDITS
ACCELERATED DEPRECIATION
USAF
PRIVATE FIRM
FOSSIL FUEL DISPLACED
COULD HAVE BEEN EXPENSED
YRS.

Figure 3-11

As a summary of results, Figures 3-12a-d present comparisons of solar thermal systems' performance costs, and returns on investment at six bases in different insolation areas. Figure 3-13 provides information on the percent of load which the optimum solar energy system will displace under the baseline assumptions. These vary from 11 to 22 percent on a 24 hour 7 day per week basis. As a first approximation, percentage of fuel diplaced for one shift operation will be somewhat less than three times the tabulated value. A five day per week duty cycle would modify the value by a factor of about 71 percent.

c. Solar Pond Analysis

The project team also conducted a brief analysis of solar pond feasibility for application #101, boiler feedwater preheat -- at Kirtland, Tinker, and Wright-Patterson. These represent a high, medium, and low ranked base in terms of solar climate. Ponds were sized to meet the entire process load -- 52,560 MilBTU per year. Neither O&M costs (probably small) nor the capital cost savings of fossil fuel plant and equipment displacement were considered. Cost factors and efficiencies were based on information provided by JPL. A discounted cash flow analysis was performed. The reader is cautioned that this analysis was based on a 1980 start date, as opposed to a 1983 start date in the SERI model. Thus, caution must be exercised in making comparisons between the findings. The results are presented in Figure 3-14.

It was found that solar ponds offer potentially attractive returns at all three bases. R.O.I.'s under a fuel displacement scenerio were 21%, 18% and 17%, respectively. Under a natural gas scenerio, the percentages were 17%, 12% and 11%, respectively.

Solar ponds at all bases and for both fuel oil and natural gas displacement, exhibit shorter payback periods than with flat plates. This is due to the fact that the initial investment, although higher than for flat plates, displaces 100% of the energy requirement. As a comparison, flat plate systems at Wright-Patterson and Kirtland displace only 11&18% of the fossil fuel, respectively. Annual R.O.I.'s on the two systems are roughly comparable.

COMPARISON OF SOLAR SYSTEMS' COST AND PERFORMANCE
AT ALTERNATIVE USAF BASES

APPLICATION 101 - MOST ATTRACTIVE (HIGHEST IROR) SYSTEM
BOILER FEEDWATER PREHEAT; PROCESS TEMP = 180°; INLET TEMP = 55°F; OUTLET TEMP = 190°F; 6 MilBTU/Hr; FUEL UTIL. EFF. = .80

Base	System Type	MilBTU/Yr Delivered Energy	Sq.Ft. of Collector	Acres Required	Annual Energy Capacity Cost ($/MilBTU/Yr)	Total Investment	IROR	NPV
Kirtland	F.P.	9411	28,571	1.3	$ 82	$769,000	29%	$2,090,000
McClellan	F.P.	8702	30,303	1.4	$ 96	$834,000	26%	$1,767,000
MacDill	F.P.	8327	32,258	1.5	$101	$839,000	23%	$1,466,000
Tinker	F.P.	7877	32,258	1.5	$108	$848,000	23%	$1,476,000
Robins	F.P.	6816	30,000	1.4	$114	$780,000	22%	$1,216,000
Wright-Patterson	F.P.	5825	39,682	1.6	$158	$918,000	19%	$ 971,000

Figure 3-12a

COMPARISON OF SOLAR SYSTEMS' COST AND PERFORMANCE
AT ALTERNATIVE USAF BASES

APPLICATION 207 - MOST ATTRACTIVE SYSTEM STEAM GEN. & INSERTION;
PROCESS TEMP = 250°F; INLET TEMP = 55°F; OUTLET TEMP = 250°F;
1 MilBTU/Hr; FUEL UTIL. EFF. = .75

Base	System Type	MilBTU/Yr Delivered Energy	Sq.Ft of Collector	Acres Required	Annual Energy Capacity Cost ($/MilBTU/Yr)	Total Investment	IROR	NPV
Kirtland	P.T.	1932	4808	.3	$137	$264,000	20%	$330,000
McClellan	P.T.	1866	5291	.3	$161	$300,000	18%	$258,000
MacDill	E.T.	1806	6711	.3	$193	$348,000	14%	$133,000
Tinker	P.T.	1569	5589	.3	$189	$296,000	15%	$159,000
Robins	E.T.	1532	6250	.3	$212	$324,000	14%	$108,000
Wright-Patterson	E.T.	1355	6944	.3	$273	$369,000	12%	$ 52,000

Figure 3-12b

COMPARISON OF SOLAR SYSTEMS' COST AND PERFORMANCE

AT ALTERNATIVE USAF BASES

APPLICATION 301 - MOST ATTRACTIVE SYSTEM PROCESS DIRECT SUPPLEMENT;
PROCESS TEMP = 250°F; INLET TEMP = 55°F; OUTLET TEMP = 270°F; .2MilBTU/Hr;
FUEL UTIL. EFF. = .60; STEAM FLASH WITH HEAT EXCHANGER

Base	System Type	MilBTU/Yr Delivered Energy	Sq.Ft.of Collector	Acres Required	Annual Energy Capacity Cost ($/MilBTU/Yr)	Total Investment	IROR	NPV
Kirtland	P.T.	385	966	.1	$138	$53,000	24%	$99,000
McClellan	P.T.	372	1064	.1	$162	$60,000	21%	$84,000
MacDill	E.T.	355	1361	.1	$199	$71,000	17%	$53,000
Tinker	P.T.	313	1124	.1	$190	$60,000	18%	$59,000
Robins	P.T.	275	1124	.1	$213	$59,000	17%	$43,000
Wright-Patterson	P.T.	230	1190	.1	$277	$64,000	15%	$31,000

Figure 3-12c

COMPARISON OF SOLAR SYSTEMS' COST AND PERFORMANCE

AT ALTERNATIVE USAF BASES

APPLICATION 401 - MOST ATTRACTIVE SYSTEM HOT WATER CONVERSION; PROCESS TEMP = 200°F; INLET TEMP = 220°F; OUTLET TEMP = 250°F; 5 MilBTU/Hr; FUEL UTIL. EFF. = .60; HOT WATER MEDIUM WITH HEAT EXCHANGER

Base	System Type	MilBTU/Yr Delivered Energy	Sq.Ft.of Collector	Acres Required	Annual Energy Capacity Cost ($/MilBTU/Yr)	Total Investment	IROR	NPV
Kirtland	P.T.	9357	24,876	1.4	$140	$1,311,000	24%	$2,380,000
McClellan	P.T.	8994	27,322	1.6	$165	$1,484,000	21%	$1,989,000
Tinker	P.T.	7575	29,070	1.7	$196	$1,486,000	18%	$1,359,000
MacDill	P.T.	7189	28,409	1.6	$199	$1,432,000	17%	$1,064,000
Robins	P.T.	6652	29,070	1.7	$220	$1,464,000	16%	$ 981,000
Wright-Patterson	P.T.	5518	30,675	1.8	$287	$1,582,000	14%	$ 662,000

Figure 3-12d

COMPARISON OF PERCENTAGE OF APPLICATION
ENERGY SUPPLIED BY SOLAR SYSTEM -
MOST ECONOMICALLY ATTRACTIVE SYSTEM
(assuming 24 hour operations 365 days per year)

Application	MilBTU/Yr Energy Consumed	PERCENTAGE OF ANNUAL ENERGY SUPPLIED BY SOLAR								
		Kirt-land	Hill	McClellan	Lowry	Tinker	MacDill	Eglin	Robins	Wright-Patterson
101	52,560	18	15	17	16	15	16	15	13	11
102	52,560	17	15	16	16	14	15	15	12	11
201	87,600	22	20	21	20	18	17	17	16	13
202	87,600	22	20	21	20	17	17	17	15	13
203	87,600	21	20	21	20	17	16	16	15	13
204	87,600	21	20	21	20	17	16	16	15	13
205	87,600	21	19	20	19	17	22	16	15	12
206	87,600	21	19	20	19	17	16	16	15	12
207	8,760	22	20	21	20	18	17	17	16	13
208	8,760	22	20	21	20	17	17	17	15	13
209	8,760	21	20	21	20	17	16	16	15	13
210	8,760	21	20	21	20	17	16	16	15	13
211	8,760	21	19	20	19	17	16	16	15	12
212	8,760	21	19	20	19	17	16	16	15	12
301	1,752	22	20	21	20	18	20	20	16	13
302	1,752	21	19	21	20	17	16	16	15	13
303	4,380	22	19	21	20	18	17	17	16	13
304	4,380	21	19	21	20	17	16	16	15	13
401	43,800	21	19	21	20	17	16	16	15	13
402	8,760	21	19	21	20	17	16	16	15	13

Figure 3-13

SOLAR POND ANALYSIS

GENERIC APPLICATION #101; 52,560 MilBTU/Yr; DISCOUNT RATE = 10%

	Pond Size (1000s sq.ft)	Pond Size (Acres)	Total Investment (@$3.25/sq.ft; in $1000s)	FUEL OIL			NATURAL GAS		
				NPV ($1000s)	R.O.I.	Payback Period (yrs.)	NPV ($1000s)	R.O.I.	Pay-back Period (yrs.)
KIRTLAND	436	8.9	1417	7748	21%	4	4623	17%	7
TINKER	661	13.5	2148	7017	18%	5	1346	12%	14
WRIGHT-PATTERSON	1042	21.3	3387	7087	17%	7	1054	11%	17

Figure 3-14

CONCLUSIONS

1. A generic analysis indicates that solar process heat investments, if carefully made, make good economic sense to USAF. The Air Force has a large number of low temperature applications which are immediately attractive. According to the baseline assessments, returns on investment of 19-29% can be realized in high insolation areas using the most favorable solar technology in low temperature applications over a 20 year life time. Even in low insolation areas, ROIs of 4-14% are projected.

2. The actual budgetary dollar savings to USAF are predicted to be very large, approximately double that of the private sector which realizes tax benefits by expensing fuels.

3. Many mid-temperature applications also show attractive returns on investment. Negative ROIs are found only in low insolation areas and areas where fuels are still relatively cheap. In medium to high insolation areas, ROIs of 10%-20% are projected compared to fuel oil, and 4-15% compared to natural gas.

4. There is no single favored technology option. Solar ponds look extremely attractive for boiler preheat loads. According to a separate analysis ROIs are on the order of 11-21 percent and payback periods are 4-17 years. On the other hand, this is not yet a proven technology and values are more speculative.

Similarly, point focussing dishes as sponsored by JPL show a great promise for near-term (1-3 years) price reduction and thus a dramatic increase in ROI. Currently, parabolic troughs are better known, better characterized, and more cost effective. The situation is extremely dynamic, however, and should be continuously monitored.

USAF will benefit from experience in the near term with all types of solar thermal process heat systems. Flat plate and parabolic troughs can be used and operationally evaluated for procurement as technology demonstration systems. Ponds and dishes can be the object of technology applications development programs for longer term assessment.

5. The reduction of risk to USAF and the external social benefits of solar energy systems represent additional, unquantified cost savings.

6. Most conceivable alterations to the baseline analysis make generic solar IPH more favorable.

7. Site-specific factors will often inhibit solar retrofit applications. The existing capital investment in mid-temperature central boiler may impose a strategy of direct steam insertion at lower solar efficiencies. The distance between the load and available land may have a similar impact. The lack of metered data on load profiles and of data on roof load tolerances will also inhibit progress through the additional tasks they impose prerequisite to a solar system design.

8. The USAF applications with the highest potential returns on investment are those

a) On bases with the best solar climate
b) Where backup fuel is most expensive
c) In low to low-mid temperature applications
d) At the application, wherever possible.

These factors should be considered in Task 2.

9. The major barrier to USAF's utilization of solar thermal process heat systems may be USAF's institutional base for managing change. Current planning and information management has evolved to meet the problems imposed by conventional technology. Data necessary to exploit alternative technologies is not reported and is therefore unavailable.

Base civil engineering expertise and knowledge of site specific factors is essential to characterize applications for site specific technologies but base engineers have little institutionalized, active role in planning. Decentralized technologies may require decentralized planning.

Process metering is essential to planning for solar application. This type of activity should be incorporated into USAF metering and energy monitoring and control programs.

10. Because the SERI PROSYS data base did not include information on power towers, analytical results are not available here. The applications for these systems (201-206 and multiples) are central steam plants. According to SERI, site factors are so predominant in projecting system feasibility that generic analysis is inappropriate. We believe that, as a first approximation, where trough or dish systems indicate a generic applicability for central plant applications, towers are worthy of detailed analysis as well. However, the construction of central solar plants seems to be the least attractive overall near-term strategy due to seasonal load variability, the inefficiencies of current distribution networks, the congestion at central locations on base, and the high first cost of a program that is relatively high risk compared to a modular approach, to gaining experience with solar thermal heat plants.

RECOMMENDATIONS

1. USAF can benefit from the utilization of solar process heat technologies. Potential benefits include both displacement of fossil fuel consumption and projected budgetary dollar savings. Therefore, USAF should attempt to gain operating experience with these technologies in the near term.

2. Because the best generic technology choices are not yet known, and may not be limited to a single technology set, USAF should seek diversified experience with a variety of systems in different applications and insolation areas.

3. In order to effectively exploit the value of these technologies, USAF must revise its energy information and management activities to incorporate a new technology planning perspective.

4. USAF should address the problems which decentralized and site specific technologies impose on planning, and determine where structural changes in responsibilities for planning and management may be implied for optimum efficiency and effectiveness.

5. Solar ponds seem to have a very large payoff potential for a limited, but generic set of USAF process heat applications. Case studies, should address this potential in detail. The technology should be followed closely. Joint experiments in this "advanced" technology area have a very high and near term payoff.

6. Current, commercially available, flat plate and parabolic trough hardware show reasonable returns on investment to USAF for immediate applications. Operational evaluation of these systems is warranted.

7. Parabolic dish systems show a potential for near term (1-3 year) price decreases. Joint technology development experiments can help realize this potential, and consequently significant savings to USAF.

8. Case study analyses are necessary to extend this generic analysis. Solar technologies are site and application specific, and site and application analyses are necessary to assess any real-world utilization of hardware. Generic analyses can only serve as guidelines to evaluate trends and to screen and select specific applications for analysis.

9. The Task II case studies of this research project should aim for diversity. The technical factors to be considered in selection are:

1. Insolation
2. Fuel price at site
3. Interface with current plant
4. Temperature of end-use

In addition, the active interest of BCE personnel is crucial to the quality of program results. For example, special metering would be extremely helpful, but will require BCE participation. BCE participation should be solicited and made one criterion for selection.

NEW TECHNOLOGY

No reportable items of new technologies were identified.